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Rheological studies on mixtures of corn starch and konjac-glucomannan

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Rheological properties of corn starch (CS) and konjac-glucomannan (KM) mixtures (total polysaccharide concentration: 3.50 wt%, CS/KM ratios: 10/0, 9/1, 8/2, 7/3, 6/4) were studied as a function of mixing ratio and storage time by measuring storage and loss shear moduli and by observing the large deformation and fracture behaviour. The viscoelastic behaviour of dispersions of CS plus water (2.10–3.50 wt%, 3.50 wt% = 10/0) was intermediate between a weak gel and an elastic gel, and dispersions of KM plus water (0.35–1.40 wt%) showed a behaviour similar to a concentrated polymer solution. The behaviour of CS and KM mixture was intermediate between a concentrated polymer solution and a weak gel. KM does not interact synergistically with CS to promote the formation of ordered structure. The breaking stress for CS and KM mixtures increased slowly with storage time than for CS alone. KM prevented syneresis of corn starch during storage. © 1998 Elsevier Science Limited. All rights reserved.

INTRODUCTION

Starch has found widespread application in the food industry. Starch and hydrocolloid mixtures are often used to modify and control the texture of food products. The addition of hydrocolloid to starch is known to increase the viscosity of starch and influence the gelatinization and retrogradation of starch. The rheological properties of mixtures of wheat starch and locust bean gum (Sajjan *et al.*, 1987; Alloncle *et al.*, 1989; Yousria *et al.*, 1994), guar gum (Christianson *et al.*, 1981; Sajjan *et al.*, 1987; Alloncle et al., 1989; Yousria *et al.*, 1994), xanthan gum (Christianson *et al.*, 1981; Alloncle *et al.*, 1991; Yousria *et al.*, 1994), sodium carboxymethyl cellulose (Christianson *et al.*, 1981), konjac flour (Yousria *et al.*, 1994), carrageenan (Tye, 1988) and of corn starch and xanthan gum, guar gum, locust bean gum (Alloncle *et al.*, 1991; Yousria *et al.*, 1994) have been reported. The rheological properties of mixtures of potato maltodextrin and gum arabic (Annable *et al.*, 1994), of mixtures of sweet potato starch and cellulose derivatives (Kohyama *et al.*, 1992) were studied. These hydrocolloids increased starch viscosity and slowed down the retrogradation of starch (Christianson *et al.*, 1981; Sajjan *et al.*, 1987; Alloncle *et al.*, 1989; Kohyama *et al.*, 1992; Yousria *et al.*, 1994).

Konjac-glucomannan (KM) is a neutral polysaccharide derived from the tuber of Amorphophallus konjac C. Koch. It forms a thermally stable gel (Konnyaku) upon addition of an alkaline coagulant and is used in traditional Japanese cooking (Nishinari *et al.*, 1992). KM has been introduced into the USA and Europe as a food additive. It forms a viscous solution when dissolved in water (Nishinari *et al.*, 1987), and is used as a thickener for soups and sauces. Recently, the interaction of KM with other hydrocolloids (e.g. carrageenan, xanthan gum, gellan gum) has been studied. It was reported that KM interacted synergistically with carrageenan (Cairns *et al.*, 1988, 1991; Nishinari *et al.*, 1992; Williams *et al.*, 1992, 1993; Kohyama *et al.*, 1993a,b, 1996), xanthan gum (Brownsey *et al.*, 1988; Williams *et al.*, 1991a,b; Shatwell *et al.*, 1991; Nishinari *et al.*, 1992). Nishinari *et al.* (1996) reported on the interaction between gellan gum and KM. The interaction of KM with CS has not yet been examined as far as the authors are aware.

In the present study, we investigated the rheological properties of CS and KM as a function of time and of mixing ratio by observing dynamic viscoelasticity and stress–strain

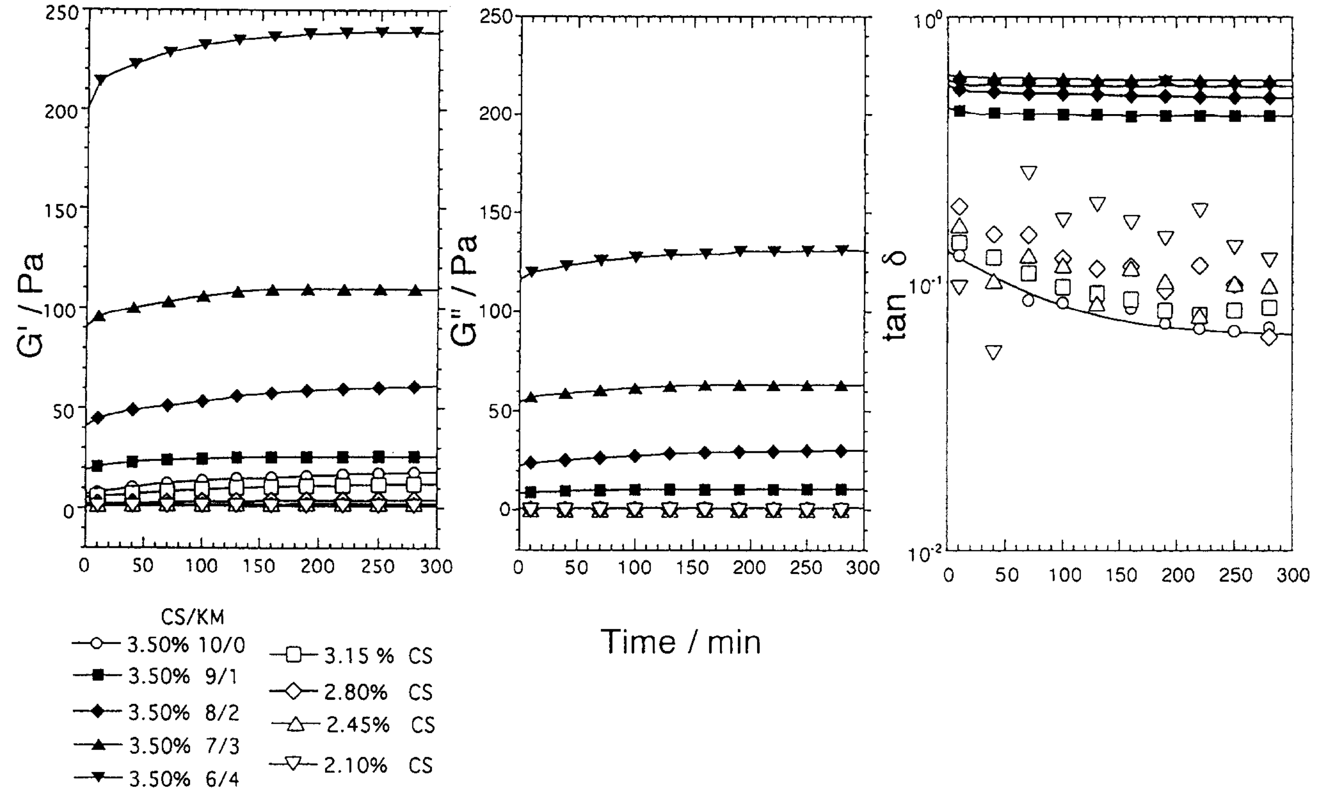

Fig. 1. Time dependence of G', G'' and tan δ for corn starch (CS) and konjac-glucomannan (KM) mixture (filled symbols) and CS plus water (open symbols). Total polysaccharide concentration and CS/KM mixing ratio: ○, 3.50 wt% 10/0; ■, 3.50 wt% 9/1; ◆, 3.50 wt% 8/2; ▲, 3.50 wt% 7/3; ▼, 3.50 wt% 6/4; □, 3.15 wt% CS; ◇, 2.80 wt% CS; △, 2.45 wt% CS; ▽, 2.10 wt% CS. Measurement temperature: 5°C, frequency: 1 rad/s.

curves. The effects of KM on the retrogradation of CS were also investigated.

EXPERIMENTAL

Material

Corn starch (CS) was a gift from Sanwa Cornstarch Co. Ltd (Nara, Japan). Konjac-glucomannan (KM) was a gift from Ogino Co. Ltd (Gunma, Japan). Moisture content of konjac-glucomannan was 7.9%. Moisture content and protein content of corn starch were 12.5% and 0.28% respectively. Amylose content of the corn starch was 25%.

Preparation of mixtures for rheological measurement

Powders of corn starch or corn starch and konjac-glucomannan mixture were dispersed in distilled water using a motorized stirrer (Shintou Science Ltd, Tokyo, Japan, HEIDON 3000H). Stirring was continued at 200 rpm for 2 h at room temperature. Then the dispersion was heated in an oil bath to 95°C for 15 min and then held at 95–98°C for 30 min. The mixture was stirred continuously at 400 rpm. The boiling distilled water was added to the hot mixture and the total polysaccharide content of the hot mixture was adjusted to 3.50 wt%. The concentration used in the present work is based on the weight of the powder of corn starch (moisture content 12.5%), and konjac-glucomannan (moisture content 7.9%). The mixing ratios of corn starch (CS) and konjac-glucomannan (KM) were CS/KM = 10/0, 9/1, 8/2, 7/3 and 6/4. Dispersions of KM plus water (0.35–1.40 wt%) and CS plus water (2.10–3.50 wt%, 3.50 wt% = 10/0) were also prepared.

Dynamic viscoelasticity

Dynamic viscoelastic measurements were carried out using a Fluids Spectrometer RFS II (Rheometrics Co. Ltd, NJ, USA) with a plate geometry (25 mm diameter) and strain of 4% (limit of linear viscoelastic strain was about 8% for the sample mixture at 5°C.). The hot sample mixture was poured directly onto the plate of the instrument, which had been kept at 5°C. Immediately the storage shear modulus G' and the loss shear modulus G'' were measured as a function of time at 1 rad/s at 5°C for 300 min. Then frequency sweep experiments (10^{-3}–10^2 rad/s) were performed at 5°C after the attainment of the plateau values (after 24 h). After 24 h the storage modulus $G'(G'1)$ at 1 rad/s with mixing ratios CS/KM = 10/0, 9/1, 8/2, 7/3, 6/4 were 27×10^2, 32×10^2, 70×10^2, 13×10^3, 23×10^3 Pa respectively. When frequency sweep experiments were performed, $G'(G'2)$ at 1 rad/s with mixing ratios CS/KM = 10/0, 9/1, 8/2, 7/3, 6/4 were 31×10^2, 30×10^2, 69×10^2, 13×10^3, 21×10^3 Pa respectively. The difference between ($G'1$) and ($G'2$) were small, G' was taken as the plateau value after 24 h.

Penetration testing

The hot sample mixtures prepared as described above were poured into moulds (50 mm diameter and 30 mm height) and held at room temperature (22°C) for 1 h and then stored at 5°C. Penetration was carried out using a Rheoner RE-3305 (Yamaden Co. Ltd, Tokyo, Japan) with a 200 g load cell and crosshead speed of 3 mm/min or 30 mm/min as a function of storage time at 5°C. The diameter of the plunger was 8 mm.

Observation of syneresis

The hot sample mixtures prepared, as described above, were poured into glass tubes (30 mm diameter and 300 mm height) and were held vertically at 5°C for 20 days. The extent of syneresis was estimated by the length of liquid phase Δh separated above the sedimented phase. The degree of syneresis was represented by $\Delta h/h_0$, where h_0 ($h_0 = 300$ mm) stands for the initial height of the sample dispersion.

RESULTS AND DISCUSSION

Fig. 1 shows the time dependence of the storage shear modulus G', the loss shear modulus G'' and the mechanical loss tangent tan δ for CS and KM mixtures (9/1–6/4) and CS plus water (2.10–3.50 wt%, 3.50 wt% = 10/0) at 5°C. The time $t = 0$ was taken as the time when the sample was set on the plate.

G' and G'' of CS plus water (2.10–3.50 wt%) was dependent on CS concentration and the modulus increased with increasing CS concentration. Fig. 2 shows the dependence of the storage shear modulus on corn starch concentration. The storage shear modulus, G' shows about a sixth power dependence on corn starch concentration. Ellis *et al.* (1985) reported that the rigidity modulus of amylose gels is strongly dependent on amylose concentration, and that amylose starts to form a gel at concentration of 1.5 wt%. Above this concentration the modulus showed a seventh power dependence on concentration. Keetels *et al.* (1996) reported that the modulus of 10–40% potato and wheat starch gels showed a linear dependence on concentration. Evans *et al.* (1979) found a linear or almost linear dependence on concentration for starch gels of potato, wheat, and maize up to 10%. A similar tendency was found for 6–30% starch gels of pea maize and potato, and for 10–25% amylose gels by Ring (1985) and Ring *et al.* (1987). Many researchers reported that G' of other biopolymer gels (e.g. gelatin, agar, casein micelle) showed a square power dependence on concentration. The concentration dependence of elastic modulus of biopolymer gels was discussed by Clark *et al.* (1985) using a cascade treatment and by Oakenfull (1984) using another model. A large slope at lower concentrations and a small slope at higher concentrations were predicted in the double logarithmic plot of G' against C/C_0, where C_0 is the critical concentration above which the system starts to form a gel. Since the corn starch concentration used in the present work was low (2.10–3.50 wt%), the high concentration dependence ($\sim C^6$) is expected.

Although dispersions of KM plus water did not form a gel, but showed a behaviour of a concentrated polymer solution as will be shown later in Fig. 6, G' and G'' of CS and KM mixture increased with increasing KM concentration as shown in Fig. 1, because those of KM plus water are far larger than those of CS plus water at 1 rad/s.

G' slightly increased with time as shown in Fig. 1. G' of CS plus water (10/0) did not attain the plateau value and increased steadily even after 300 min. For CS and KM mixture G' increased steadily with time and then levelled off. The loss tangent, tan δ decreased with time. Both moduli for CS and KM mixture were larger than those for a dispersion of CS plus water with the same content; however, since KM mainly contributes to G'' rather than to G', the value of tan δ increased with increasing content of KM. Mixtures with lower KM content are more solid-like than those with higher KM content.

Fig. 3 shows the time dependence of $(G'_t - G'_0)/G'_0$ for CS plus water (10/0) and CS and KM mixture (9/1–6/4), where G'_t/G'_0 denotes the value of G' at time $t = t$ divided by G' at time $t = 0$. $(G'_t - G'_0)/G'_0$ for CS and KM mixture increased and attained plateau values faster than that for CS plus water. We suppose that two reactions with different rate constants are taking place at the same time with increasing of G' as a function of time. These curves shown in Fig. 3 could be well approximated by the following equation:

$$G(t) = G_0' + G'_{1S}(1 - e^{-k_1 t}) + G'_{2S}(1 - e^{-k_2 t})$$

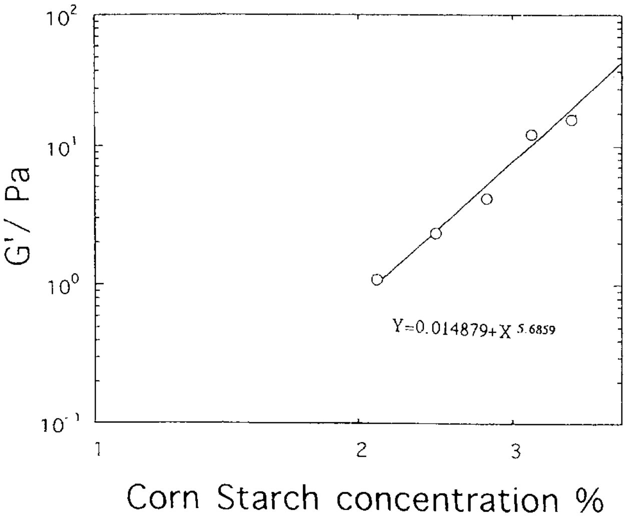

Fig. 2. Double logarithmic plot of storage shear modulus of CS plus water and corn starch concentration. Measurement temperature: 5°C, frequency: 1 rad/s.

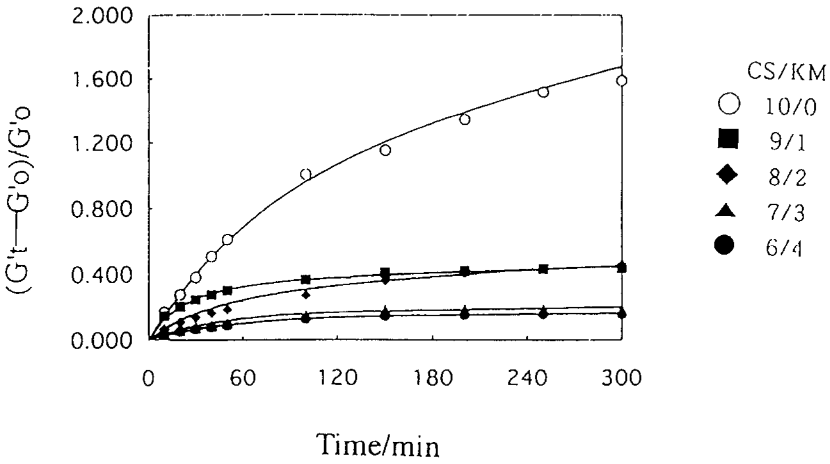

Fig. 3. Time dependence of $(G'_t - G'_0)/G'_0$ for CS plus water and CS and KM mixture. Total polysaccharide concentration 3.50 wt%. CS/KM mixing ratio: ○, 10/0; ■, 9/1; ◆, 8/2; ▲, 7/3; ●, 6/4. Measurement temperature: 5°C, frequency: 1 rad/s.

where G'_0 is the value of G' at time $t = 0$, and k_1 and k_2 are the rate constants ($k_1 \gg k_2$) respectively. They are determined from the best fitting of the experimental and calculated values of G'. Fig. 4 shows time dependence of experimental and calculated values of G' for CS and KM mixture with CS/KM = 9/1. The rate constants k_1 for CS and KM mixtures with mixing ratios 10/0, 9/1, 8/2, 7/3, 6/4 were 0.01, 0.06, 0.03, 0.03, 0.02 s^{-1}, while the values of k_2 were 0.001, 0.007, 0.004, 0.003, 0.002 s^{-1} respectively. Both the rate constants k_1, k_2 for CS/KM = 9/1 were largest of all: it was suggested that the retrogradation of CS/KM = 9/1 proceeded faster than other systems. Since k_1 and k_2 values for CS plus water (10/0) were smaller than those of CS and KM mixtures, it was suggested that the retrogradation of CS plus water proceeded slowly and did not attain plateau values for 300 min. In other words, at the beginning, the retrogradation of CS and KM mixture proceeded faster than that for CS plus water, and it was suggested that konjac-glucomannan promoted starch retrogradation at the beginning of retrogradation, and then retarded it slightly during longer storage. The retrogradation of starch was promoted over short storage times by the presence of konjac-glucomannan, because the effective concentration of starch was increased by the immobilization of water by konjac-glucomannan. Is it

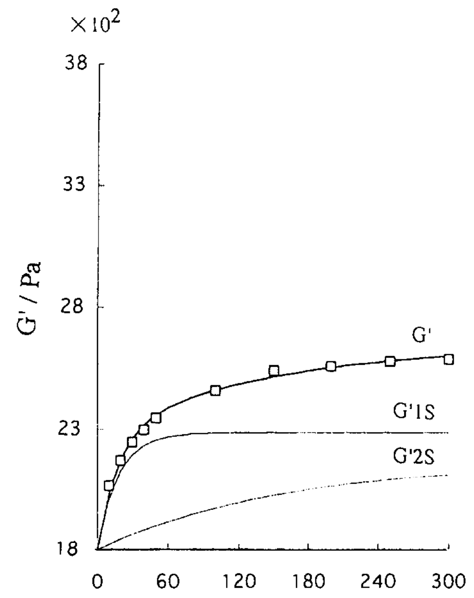

Fig. 4. Time dependence of experimental and calculated values of G' for CS and KM mixture with CS/KM = 9/1. Open symbols are the experimental values. The solid line represents calculated values of G'. The dotted lines show calculated values of G'_{1S} and G'_{2S}.

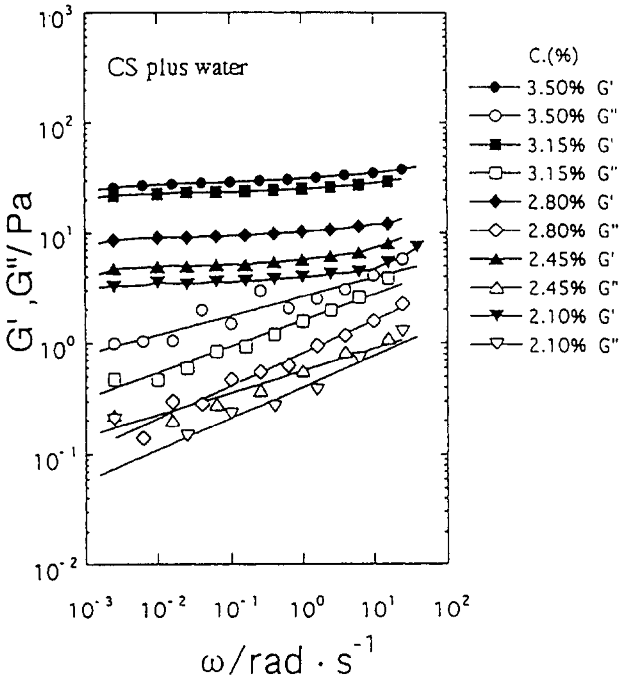

Fig. 5. Frequency dependence of G' and G'' for CS plus water. C, concentration of corn starch: ●, 3.50 wt% G'; ○, 3.50 wt% G''; ■, 3.15 wt% G'; □, 3.15 wt% G''; ◆, 2.80 wt% G'; ◇, 2.80 wt% G''; ▲, 2.45 wt% G'; △, 2.45 wt% G''; ▼, 2.10 wt% iG'; ▽, 2.10 wt% G''.

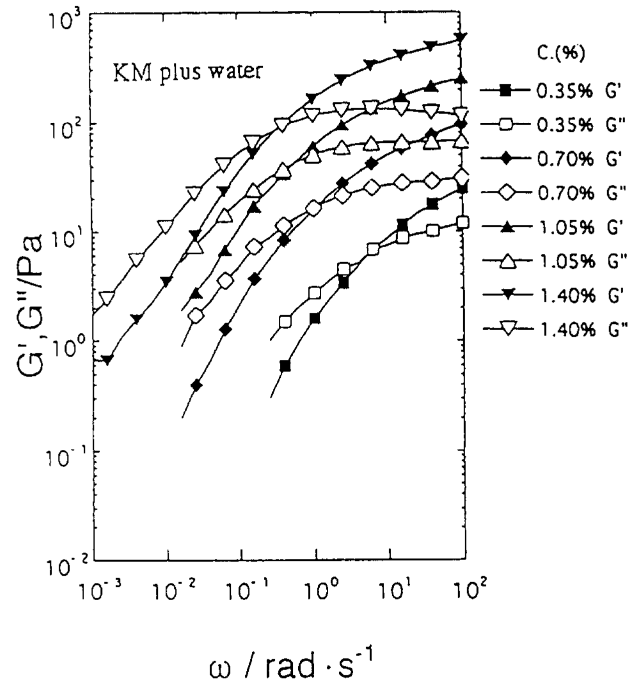

Fig. 6. Frequency dependence of G' and G'' for KM plus water. C, concentration of konjac-glucomannan: ■, 0.35 wt% G'; □, 0.35 wt% G''; ◆, 0.70 wt% G'; ◇, 0.70 wt% G''; ▲, 1.05 wt% G'; △, 1.05 wt% G''; ▼, 1.40 wt% G'; ▽, 1.40 wt% G''.

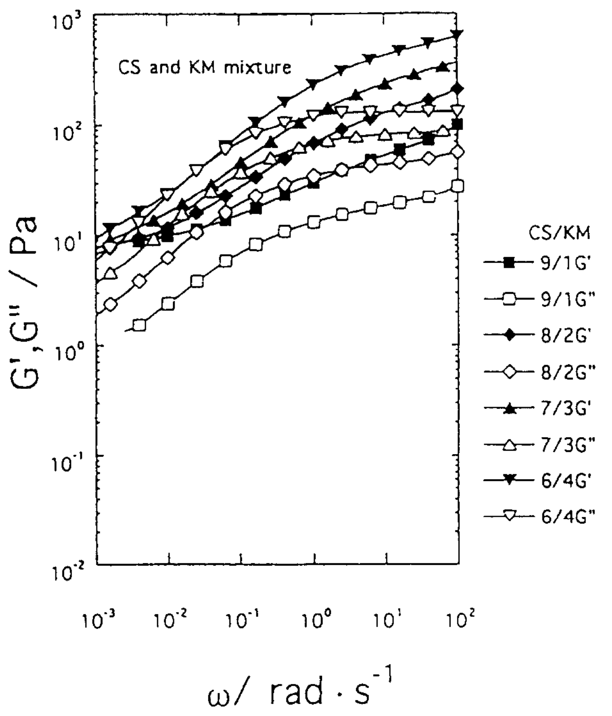

Fig. 7. Frequency dependence of G' and G'' for CS and KM mixture. Total polysaccharide concentration: 3.50 wt%. CS/KM mixing ratio: ■, 9/1 G'; □, 9/1 G''; ◆, 8/2 G'; ◇, 8/2 G''; ▲, 7/3 G'; △, 7/3 G''; ▼, 6/4 G'; ▽, 6/4 G''.

possible that konjac-glucomannan molecules interact with corn starch molecules and promote structure-ordering? This possibility should be excluded, as will be discussed later, because of the frequency dependence of G' and G'', as will be shown in Fig. 7. This is also consistent with the experimental observation that the endothermic enthalpy accompanying the gelatinization of starch per unit mass of starch was independent of starch content in CS and KM mixtures (Yoshimura *et al.*, 1996). In a previous report, effects of KM on retrogradation of CS were studied as a function of storage time by measuring force–deformation curves, dynamic viscoelasticity, and differential scanning calorimetry (DSC). A mixed gel of CS and KM (total polysaccharide concentration, 15 wt%)

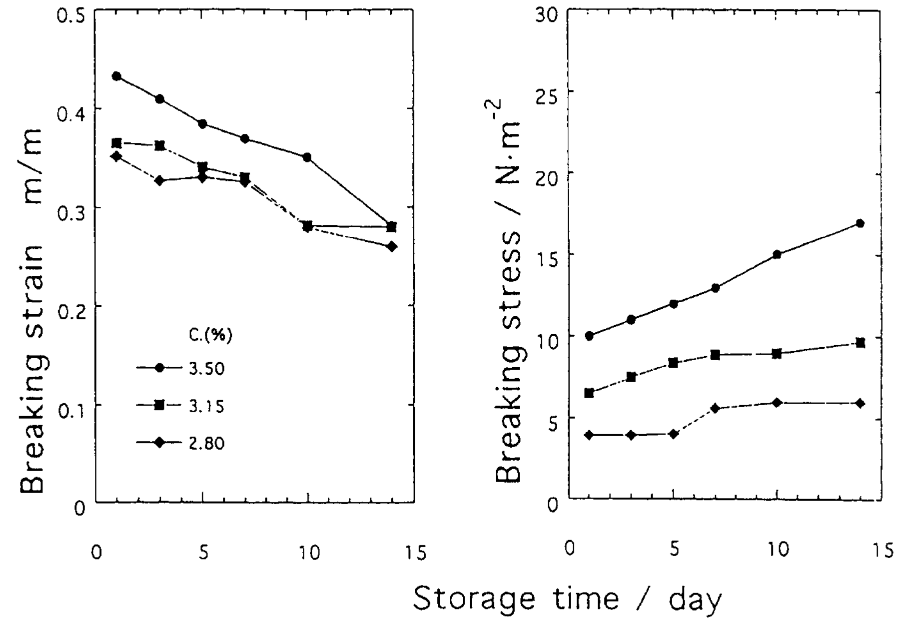

Fig. 8. Fracture behaviour in penetration of CS plus water. C, concentration of corn starch: ●, 3.50 wt%; ■, 3.15 wt%; ◆, 2.80 wt%. Measurement temperature: 5°C; storage temperature: 5°C; crosshead speed: 30 mm/min.

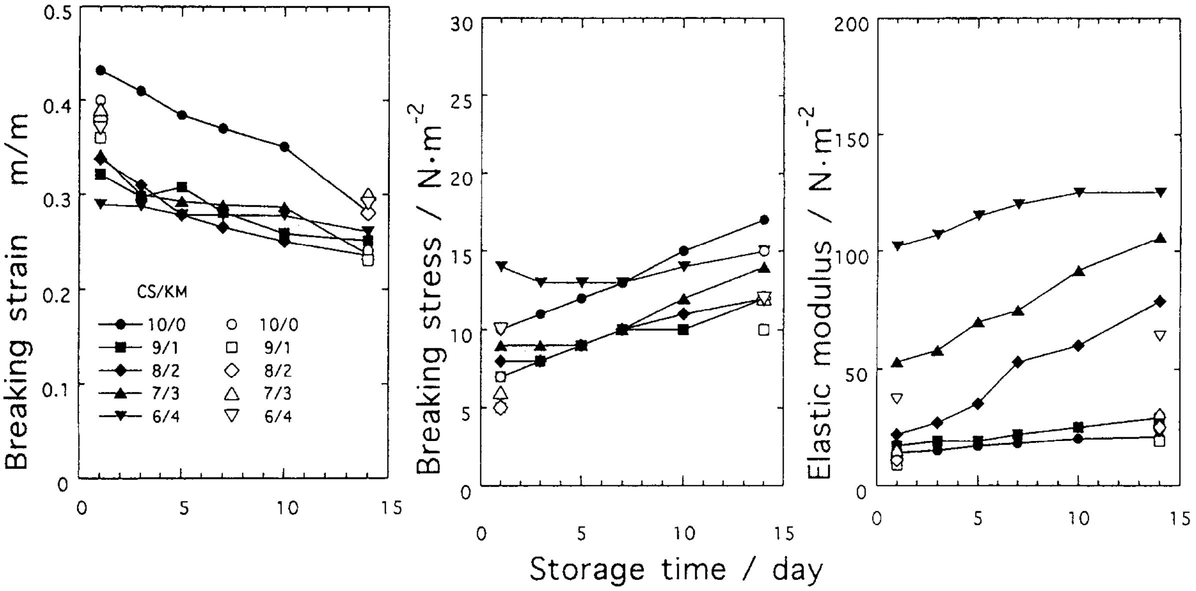

Fig. 9. Fracture behaviour in penetration of CS and KM mixture. Total polysaccharide concentration: 3.50 wt%. CS/KM mixing ratio: ●, 10/0; ■, 9/1; ◆, 8/2; ▲, 7/3; ▼, 6/4; ○, 10/0; □, 9/1; ◇, 8/2; △, 7/3; ▽, 6/4. Filled symbols: crosshead speed of 30 mm/min. Open symbols: crosshead speed of 3 mm/min. Measurement temperature: 5°C, storage temperature: 5°C.

stored for 1 day showed larger gel strength, Young's modulus, storage and loss Young's moduli than a gel of CS plus water. However, the breaking stress for mixed gel of CS and KM increased slowly with storage time compared with a gel of CS plus water, and enthalpies of CS–KM–water mixtures (total polysaccharide concentration, 33 wt%) stored for 14 days were slightly smaller than that of CS plus water. From the rheological and DSC changes it is suggested that KM promoted CS retrogradation during short-term storage and then retarded it slightly during longer storage times. Is this due to the dilution of CS concentration by the exuded water from KM? This possibility should be excluded because the syneresis of CS is prevented by KM, as will be shown in Fig. 11. The effective concentration of CS plus water (10/0) after storage for 14 days might increase because water was exuded and the system was separated into aqueous phase and sedimented phase as shown in Fig. 11.

G' and G'' for KM plus water (0.70–1.40 wt%) remained almost constant during 300 min (data not shown) indicating that neither conformational change nor structure ordering occurs during the storage.

Figs. 5 and 6 show the mechanical spectra for CS plus water and KM plus water after the attainment of the plateau values of the storage shear modulus. For CS plus water (2.10–3.50%) the storage shear modulus G' remained almost constant within the frequency range observed, while the loss shear modulus G'' increased slightly with increasing frequency. Moreover, $\tan\delta = G''/G'$ values for CS plus water are between 0.02 and 0.2. This behaviour may be classified rheologically as the intermediate between a weak gel and an elastic gel (Morris, 1983; Clark *et al.*, 1987). In contrast, the behaviour of KM plus water (Fig. 6) is typical of a concentrated polymer solution. In concentrated polymer solutions the response is liquid-like, i.e. G'' is larger than G' and both moduli increase with increasing frequency at lower frequencies, whilst the behaviour approaches that of solid-like materials, i.e. G' is larger than G'', and both moduli become frequency independent at higher frequencies. The molecular chains can disentangle and rearrange during the long period of oscillation, so G'' is larger than G' at lower frequencies in concentrated polymer solutions, while at higher frequencies molecular chains cannot disentangle during the short period of oscillation, so G' is larger than G'', because the entanglement points play the role of a temporary cross-linking junction zone. Moreover, the cross-over frequency of G' and G'' shifted to lower frequencies with increasing KM concentration as expected.

Fig. 7 shows the mechanical spectra for CS and KM mixture after the attainment of plateau values of storage shear modulus. At lower frequencies than 10^{-1} rad/s G'' for CS and KM mixture decreased monotonically with decreasing frequency; however, G' does not decrease so much as G''. This behaviour may be classified rheologically as intermediate between a concentrated polymer solution and a weak gel (Morris, 1983; Clark *et al.*, 1987). Although G' of CS and KM mixture increased with increasing content of KM at higher frequencies, the plateau of G' observed for CS plus water at lower frequencies tended to disappear with increasing content of KM. For example, at lower frequencies below 10^{-2} rad/s, G' for 3.15% CS plus water (filled squares in Fig. 5) is larger than those for 3.15%CS + 0.35%KM (CS/KM = 9/1, G', filled squares in Fig. 7), indicating that KM inhibits the formation of three-dimensional networks of CS. At higher frequencies this situation is reversed, while at lower frequencies G'' for a mixture is larger than those for CS plus water indicating that KM contributes to the mixture a viscous component rather than an elastic component to the mixture. This is interpreted as follows. Since CS plus water behaves as the intermediate between a weak gel and an elastic gel (i.e. weak network structure), KM behaves only as concentrated polymer solution and does not form a network (i.e. these are only entanglement of KM chains). Since the molecular weight of KM seems to be very high, G' and G'' of CS and KM mixtures increase with increasing content of KM, but it was not possible to make a mixture with higher KM content than CS/KM = 6/4. From these observations, it is suggested that KM does not interact synergistically with CS to promote the formation of an ordered structure and that the phase arrangement of the two components in the system is not a bicontinuous arrangement but a composite gel with one of the components (CS) forming a continuous phase because KM does not form a gel in the absence of alkaline coagulant.

Fig. 8 shows the change in behaviour in comparison with time for CS plus water (2.80–3.50 wt%). Breaking strain decreased monotonically, while breaking stress increased monotonically with storage time, indicating that gels of CS plus water became harder and brittle. A similar tendency has been reported for potato and wheat starch gels (Keetels *et al.*, 1996). Both breaking strain and breaking stress for CS plus water increased with increasing corn starch concentration. A similar tendency was found for polyvinyl alcohol (PVA) gels; breaking extension and force increased with increasing PVA concentration (Watase *et al.*, 1985). This is different from an observation for 10–40% potato starch gels; a decrease in breaking strain and an increase in breaking stress were found as the starch concentration increased (Keetels *et al.*, 1996). For agar-agar gels, breaking force increased and breaking strain decreased with increasing concentration (Nishinari *et al.*, 1980). These observations suggest that the breaking stress of a polymer gel always increases with increasing concentration of a polymer, while whether the breaking strain increases or decreases with increasing concentration of a polymer might be dependent on the type and concentration of a polymer.

Fracture behaviour in penetration measurements for CS and KM mixture are shown in Fig. 9. Filled symbols represent the values observed at a compression rate of 30 mm/min, and open symbols represent the value at 3 mm/min. Force–deformation curves (after storage for 1 day and 14 days at 5°C) for CS and KM mixture are shown in Fig. 10. Mixture with CS/KM = 6/4 showed smaller breaking strain and larger breaking stress and elastic modulus than CS plus water (10/0) after 1, 3, and 5 days of storage. The force–deformation curve for CS plus water (10/0) shows a steep decrease in force at the breaking point, while CS and KM mixtures (with CS/KM = 7/3, 6/4) show a gradual decrease in force. From these observation of the force–deformation curves, it was suggested that KM did not interact synergistically with CS to form a more elastic gel. The breaking stress and elastic modulus were smaller at the cross-head speed of 3 mm/min than at 30 mm/min as shown in Fig. 8. For the cross-head speed of 30 mm/min the elastic modulus increased markedly with increasing KM concentration. This tendency corresponds well with the observation within the linear viscoelastic region that G' and G'' of CS and KM mixture increased with increasing KM concentration as shown in Fig. 1. Although G' increased markedly with increasing KM concentration at higher frequencies, G' were small and increased slightly at lower frequencies as shown in Fig. 7. The breaking stress for mixture with CS/KM = 6/4 increased slowly with storage time in comparison with CS plus water (10/0). Roulet *et al.* (1988) carried out compression tests to examine the retrogradation of 40 and 50% wheat starch gels. They reported that the compression modulus increased with storage time at the initial stage, and then approached an asymptotic value. In the present study, however, breaking stress for CS plus water increased with time during 14 days of storage at 5°C and did not attain a plateau value, because corn starch concentration was very low.

Fig. 11 shows the change in syneresis of CS plus water and CS and KM mixture with storage time at 5°C. For CS plus water syneresis proceeded with time. The degree of syneresis increased with decreasing corn starch concentration. For KM plus water (1.50 wt%) syneresis was not observed at all during 20 days of storage at 5°C (data not shown). The syneresis of CS and KM mixture was prevented by the addition of a small amount of konjac-glucomannan.

Konjac-glucomannan had some effects on corn starch behaviour and retrogradation rates. It is well known that

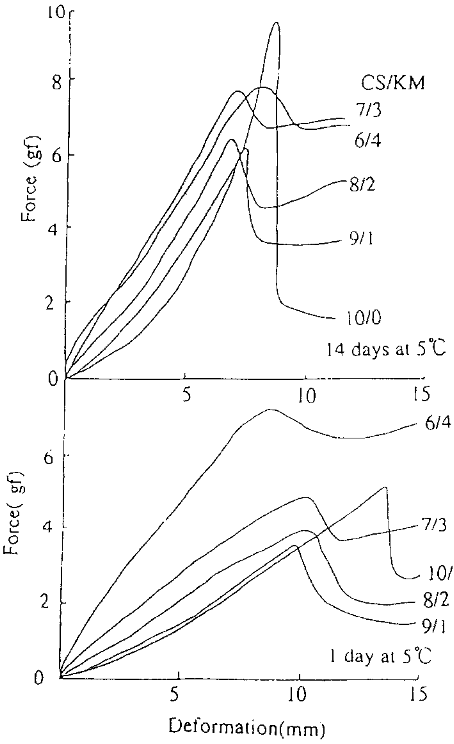

Fig. 10. Force–deformation curves in penetration for CS and KM mixtures.

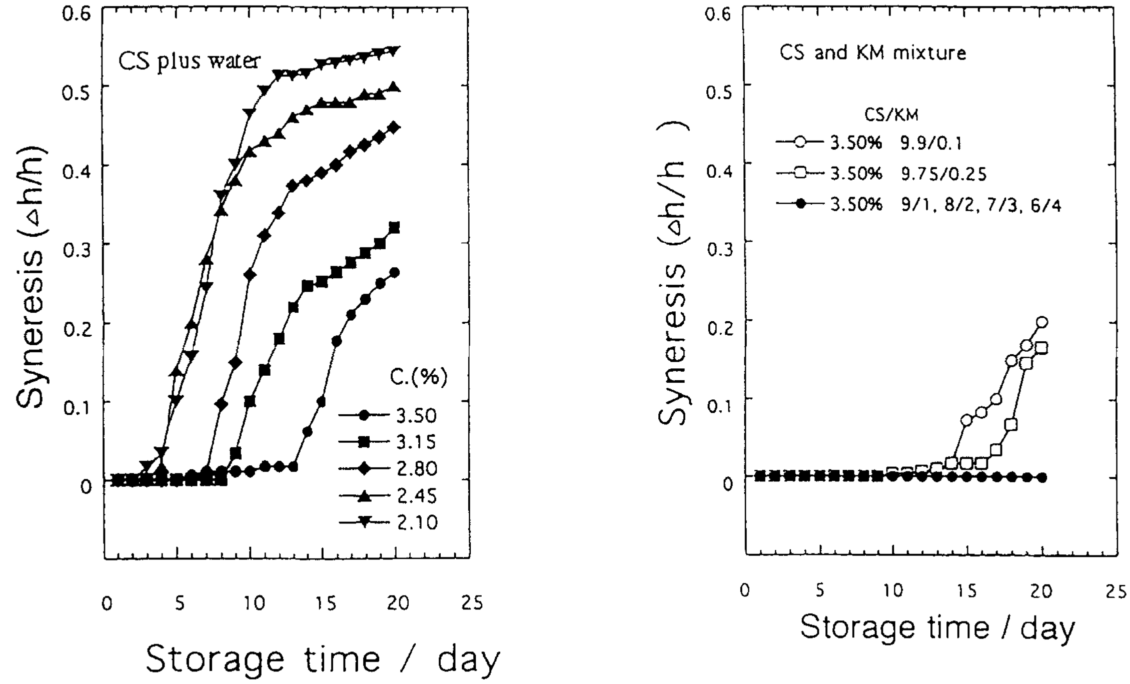

Fig. 11. Syneresis of CS plus water, CS and KM mixture. *C*, concentration of corn starch: ●, 3.50 wt%; ■, 3.15 wt%; ♦, 2.80 wt%; ▲, 2.45 wt%; ▼, 2.10 wt%. CS/KM mixing ratio: O, 3.50 wt% 9.9/0.1; □, 3.50 wt% 9.75/0.25; ●, 3.50 wt% 9/1, 8/2, 7/3, 6/4.

starch is composed of amylose and amylopectin. The retrogradation of starch proceeds in two stages (Miles et al., 1985). In the first stage, the rigidity and crystallization of starch gels develop quickly as a result of amylose gelation. In the second stage, further crystallinity develops slowly in the amylopectin region. According to Alloncle et al. (1989), the addition of galactomannan to starch promoted amylose gelation; however, the incorporation of another polysaccharide depressed final gel properties markedly. They suggested that the depression in final gel properties was due to incompatibility between the galactomannan and amylose.

We found that the high water holding capacity of konjac-glucomannan prevented syneresis (Fig. 11). The effective concentration of corn starch may be increased by the addition of KM. KM might initially promote retrogradation by absorbing water from mixtures of CS and KM. The shear storage modulus for CS and KM mixtures increased faster than that for CS plus water as a function of time during retrogradation time, and then levelled off (Figs. 1, and 3). It was suggested that konjac-glucomannan promoted the gelation of amylose in corn starch. However, the breaking stress for CS and KM mixture (with CS/KM = 6/4) increased slowly with storage time in comparison with CS plus water (10/0) (Fig. 9) and the syneresis of corn starch was prevented by a small amount of konjac-glucomannan during storage (Fig. 11). It was suggested that konjac-glucomannan slowed down the retrogradation rate of corn starch during longer storage. Konjac-glucomannan did not interact synergistically with corn starch to promote the formation of ordered structures (Figs. 5–7). The phase arrangement of the two components in the system is not a bicontinuous arrangement but a composite gel with one of the components (CS) forming a continuous phase. KM does not form a gel in the absence of alkaline coagulant, and dispersed as a sol phase in the network of CS.

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